The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

Effect of Endodontic Access on the Failure Load of Lithium Disilicate and Resin Nano-ceramic CADCAM Crowns

Is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyright owner.

CPT Christopher T. Lund, DDS
AEGD-2 Hawaii
Uniformed Services University
Date: **06/09/2016**

Uniformed Services University
of the Health Sciences

Manuscript/Presentation Approval or Clearance

INITIATOR

1. USU Principal Author/Presenter: **CPT Christopher T. Lund, DDS**

2. Academic Title: **AEGD-2 Resident**

3. School/Department/Center: **AEGD-2 Hawaii, Army PDS, USU PDC**

4. Phone: **218-341-4486**

5. Type of clearance: ___Paper _X_Article __ Book ___Poster ___Presentation
   __Workshops ___Abstract __Other

6. Title: **Effect of Endodontic Access on the Failure Load of Lithium Disilicate and Resin Nano-ceramic CADCAM Crowns**

7. Intended publication/meeting: **Academy of General Dentistry**

8. "Required by" date: **16 June 2016**

9. Date of submission for USU approval: **09 June 2016**

CHAIR/PROGRAM DIRECTOR OR DEPARTMENT HEAD APPROVAL

1. Name: **COL Peter H. Guevara**

2. School/Dept.: **AEGD-2 Hawaii, Army PDS, USU PDC**

3. Date: **09 June 2016**

***Note:** *It is DoD policy that clearance of information or material shall be granted if classified areas are not jeopardized, and the author accurately portrays official policy, even if the author takes issue with that policy. Material officially representing the view or position of the University, DoD, or the Government is subject to editing or modification by the appropriate approving authority.*

Chair/Department Head Approval: Peter H. Guevara Date 13 JUN 16

COMMANDER APPROVAL

1. Name: **COL David A. Mott**

2. School (if applicabl)/Location: **AEGD-2 Hawaii, Army PDS, USU PDC**

3. Date: **09 June 2016**

4. Higher approval clearance required (for University-, DoD- or US Gov't-level policy, communication systems or weapons issues review).

***Note:** *It is DoD policy that clearance of information or material shall be granted if classified areas are not jeopardized, and the author accurately portrays official policy, even if the author takes issue with that policy. Material officially representing the view or position of the University, DoD, or the Government is subject to editing or modification by the appropriate approving authority.*

Commander Approval: DAM D.D.A. Mott Date: 14 Jun 16

DAVID A. MOTT
COL, DC
Commanding

SERVICE DEAN APPROVAL

1. Name: Douglas D. Lancaster, COL, DC

2. School (if applicable): Army Post Graduate Dental School

3. Date: 3 August 2016

4. Higher approval clearance required (for University-, DoD- or US Gov't-level policy, communications systems or weapons issues review).

***Note:** *It is DoD policy that clearance of information or material shall be granted if classified areas are not jeopardized, and the author accurately portrays official policy, even if the author takes issue with that policy. Material officially representing the view or position of the University, DoD, or the Government is subject to editing or modification by the appropriate approving authority.*

Service Dean Approval LANCASTER.DOUGLAS.DUNN.1120129313 Date:

Digitally signed by LANCASTER.DOUGLAS.DUNN.1120129313
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=LANCASTER.DOUGLAS.DUNN.1120129313
Date: 2016.08.03 12:27:35 -05'00'

PDC DEAN APPROVAL

1. Name:

2. School (if applicable):

3. Date:

4. Higher approval clearance required (for University-, DoD- or US Gov't-level policy, communications systems or weapons issues review).

***Note:** *It is DoD policy that clearance of information or material shall be granted if classified areas are not jeopardized, and the author accurately portrays official policy, even if the author takes issue with that policy. Material officially representing the view or position of the University, DoD, or the Government is subject to editing or modification by the appropriate approving authority.*

Dean Approval______________________________ Date: ____________________

VICE PRESIDENT FOR EXTERNAL AFFAIRS ACTION

1. Name:

2. Date:

3. __USU Approved **OR**__DoD Approval/Clearance required

4. __Submitted to DoD (Health Affairs) on (date):

    OR __Submitted to DoD (Public Affairs) on (date):

5. __DoD approved/cleared (as written) **OR** __DoD approved/cleared (with changes)

6. DoD clearance/date:

7. DoD Disapproval/date:

***Note:** *It is DoD policy that clearance of information or material shall be granted if classified areas are not jeopardized, and the author accurately portrays official policy, even if the author takes issue with that policy. Material officially representing the view or position of the University, DoD, or the Government is subject to editing or modification by the appropriate approving authority.*

External Affairs Approval ____________________________Date:________________

Effect of Endodontic Access on the Failure Load of Lithium Disilicate and Resin Nano-ceramic CADCAM Crowns

Christopher Lund, DDS[a], Peter Guevara, DDS[b], Mike Lustik, MS[d], Wayne Ichimura, MS[e] Uniformed Services University of the Health Sciences, Bethesda, MD; Schofield Barracks Dental Clinic, Schofield Barracks, HI; Tripler Army Medical Center, Honolulu HI

Introduction: New materials and equipment for CADCAM crowns have increased the efficiency and quality of digital dentistry. Lithium disilicate has become an extremely popular all-ceramic CADCAM material due to its high strength and esthetics. In addition, various resin-nanoceramic materials have also demonstrated some promising properties for same-day CADCAM crowns. However, with any crown preparation of a vital tooth, there is always a risk that root canal therapy may be needed following crown cementation. Currently, there is no consensus on whether a crown needs to be replaced following the completion of root canal therapy. The aim of this study was to evaluate the effect of endodontic access preparation and repair on the failure load of lithium disilicate crowns and resin nano-ceramic.

Objective: It was hypothesized that there would be no difference in the load to failure between the intact and repaired samples for each material.

Methods: A mandibular molar crown was designed on the Sirona CEREC Omnicam unit and used to mill 40 e.max CAD and 40 Lava Ultimate crowns. Crowns were cemented onto 80 identical PMMA resin dies with Multilink Automix resin cement. A standardized endodontic access preparation was made in half the samples and restored with Luxacore composite resin. All crowns were then subjected to an occlusal load until failure with from a hydraulic testing machine.

Results: Based on the Wilcoxon rank sum test, the failure load was significantly higher for the IPS e.max CAD compared to Lava Ultimate for both intact and repaired groups. (median=2485 vs. 1138 for intact, $p<0.001$, and median=1915 vs. 1164, $p<0.001$ for repaired). For e.max CAD the failure load was significantly higher for intact compared to repaired (median=2485 vs. 1915, $p=0.002$). However, there was no significant difference between intact and repaired for Lava Ultimate (median=1138 vs. 1164, $p=0.860$).

Conclusion: Repair of Lithium Disilicate and Resin Nano-ceramic CADCAM crowns may provide a serviceable restoration under normal occlusal loads. Replacement would be prudent in cases where parafunctional occlusal loading is suspected, the crown was not adhesively cemented, or an obvious defect in existing crown.

INTRODUCTION

Milled CADCAM crowns have become very popular in recent years as new materials and equipment have increased the ease and quality of chair-side digital dentistry. Many of these CADCAM materials require substantial tooth reduction with a minimum of 1.5mm-2mm occlusal reduction and 1mm margins circumferentially. With any crown preparation on a vital tooth, the patient should be informed about the risk of pulpal problems requiring root canal therapy following crown cementation. In a systematic review of crown complications, Goodacre and colleagues found that the need for root canal treatment for single crowns was 1-3%.[1] Another study found that 4% of teeth with single crowns underwent pulpal necrosis and required root canal treatment.[2]

Currently, there is no consensus on whether a crown needs to be replaced after the completion of root canal therapy. A research survey of general dentists, endodontists and prosthodontist, found differing opinions on whether or not a crown should be replaced following. The results showed that prosthodontists were most likely to advocate for replacement.[3] To date, little research has been conducted to investigate the effects of endodontic access preparations on newer monolithic CADCAM crown materials.

The debate on whether or not to replace a ceramic crown following endodontic therapy is not a new one. In 1961, Michanowicz et al. proposed a technique for conservative access of porcelain jacket crowns with the intent of preserving the crown.[4] In 1989, Sutherland et al. examined the effect of endodontic access on Dicor feldpathic crowns fabricated for a variety of extracted teeth. The study concluded that high speed diamonds should be used with copious water spray to decrease the incidence of chipping and catastrophic porcelain fracture. They found that fracture rates upon access were tooth dependent, with mandibular incisors having a 50% fracture rate upon access.[5] Cohen et al. also looked at fracture rates during access of Dicor crowns and found that a chattering effect during access may loosen the Zinc Phosphate cement layer and contribute to porcelain fracture. They proposed that new methods of resin bonding may help overcome this problem.[6]

Some have postulated that the type of bur used for access may make a difference in incidence of chipping or fracture in all-ceramic crowns. One study found a higher incidence of fractures and craze lines when carbide burs were used to access through porcelain.[4] However, Haselton et al. found no significant differences when carbides and diamods were used to access luecite reinforced crowns.[7] Recently, Qeblawi et al found that diamonds with grits 150µm or higher resulted in decreased failure loads compared to those accessed with 126µm.[8] Sabourin et al. described a technique using air abrasion to access ceramic crowns. No cracking, chipping or catastrophic fracture occured, but the technique took significantly longer to complete.[9]

The advent of stronger all-ceramic materials has further complicated this debate of whether to repair the access or replace the entire crown. Davis described a technique for providing endodontic therapy for teeth with ceramic crowns using a round-ended, bullet shaped diamond with copious water spray. He advocated that the access be made at 90° to the ceramic surface and be at least 2mm from any margin.[10] Wood et al. compared the effect of endodontic access on feldspathic-veneered zirconia and alumina copings and concluded that access repair would only provide a suitable interim restoration, and advocated for replacement.[11] However, monolithic ceramics may be affected differently than veneered ceramics following endodontic access. To date, no study has evaluated the potential differences.

Lithium disilicate has become an extremely popular all-ceramic material for CADCAM and heat pressed applications due to its balance between strength and esthetics. Unlike other monolithic feldspathic or luecite-reinforced ceramics which must be adhesively cemented to withstand occlusal loads, lithium disilicate exhibits high fracture loads even when conventionally luted.[12]

Two recent studies have sought to better understand how the strength of lithium disilicate crowns is affected by endodontic access preparations. Qeblawi et al. found no significant difference between intact and repaired lithium disilicate crowns that had been adhesively cemented.[8] Bompolaki et al.

compared the effect of endodontic access on both heat pressed and milled lithium disilicate crowns and found that only pressed crowns showed a significant decrease in strength. Despite the difference, the pressed crowns still had higher fracture resistance than the milled crowns. [13] Both studies concluded that repair of lithium disilicate crowns could still produce a serviceable restoration.

In addition to millable ceramics, various resin-nanoceramic materials have also emerged as options for same-day CADCAM restorations. Though relatively new and less well studied, they have demonstrated some promising properties. One study found that resin-nanoceramic crowns demonstrated higher flexural strength and modulus of resilience when compared with feldpathic, luecite-reinforced, and earlier resin CADCAM crowns. The study also found smoother milled margins for the resin crowns compared to ceramic.[14] Another study examining the need for cuspal coverage of endodontically treated teeth found that cuspal coverage restorations fabricated with resin-ceramic hybrid CADCAM materials had higher fracture strength than leucite reinforced CADCAM restorations.[15]

The likelihood of hybrid resin-ceramic crowns requiring endodontic therapy following crown preparation is probably similar to all-ceramic crowns because of similar preparation requirements. However, to date, no studies have looked at the effect of endodontic access on these materials. Manufacturers maintain that they can be repaired with composite resin, but don't specifically address this issue.

The aim of this present study was to evaluate the effect of endodontic access on failure load of resin nanoceramic and lithium disilicate crowns. It was hypothesized that there would be no difference in the load to failure between the intact and repaired samples for each material. Similarly, it was hypothesized that there would be no difference in load to failure between the two crown materials.

MATERIALS AND METHODS

A power analysis (power=0.8) with $\alpha=0.05$ was used to determine the sample size for the test groups. It was determined that each test group would need 20 samples for a total of 80 specimens to detect a 20 percent difference between groups in load to failure.

An ideal CADCAM all ceramic mandibular molar crown preparation from a Sirona teaching cast was scanned with the Sirona Omnicam system. A mandibular molar crown was designed to fulfill the material requirements of Lava Ultimate (3M Espe) and IPS e.max CAD (Ivoclar Vivodant). Fourty crowns of each material were milled with a CADCAM milling unit (Cerec MC XL, Sirona). Lava Ultimate Crowns were polished for a uniform 2 min with the Diashine Lava Ultimate System. Periodic emersion into room temperature water was used to prevent overheating of the material. IPS e.max crowns were polished for 1 min with both maroon and yellow Dialite rubber diamond points for a total polish time of 2 min. Periodic water cooling was also used as described above. IPS e.max crowns were then crystallized and glazed at 840^{o}C for approximately 23min. (Programat EP 5000, Ivoclar Vivadent).

The same stone die mentioned above was scanned and used to mill 80 identical PMMA resin dies from resin pucks with a Wieland milling machine (Fig. 1). Resin dies were embedded into a resin base of uniform diameter for stabilization (EpoxiCure 2, Buehler). All dies remained the same height. The resin bases were allowed to cure for 24 hours under ventilation prior to cementation of the crowns (Fig. 2).


Figure 1. PMMA Resin Puck with 15 identical dies following milling process.

Lava Ultimate crowns were air abraided with Al_2O_3 particles (50-100μm) at 50psi for 20 seconds and steam-cleaned prior to cementation. IPS e.max CAD crowns were etched with 4.5% hydrofluoric acid gel (IPS ceramic etching gel, Ivoclar Vivadent) for 20 seconds. All crowns were silanated for 60 seconds (Monobond Plus, Ivoclar Vivodent). An acidified primer/ adhesive was applied to each resin die for 30 seconds and gently air dried (Multilink A+B pimer, Ivoclar Vivadent). Dual-polymerizing resin cement was applied to each of the crowns (Multilink Automix Next Generation, Ivoclar Vivadent). After complete seating and excess removal, a 49 N occlusal load was applied to during 20 seconds of LED light polymerization from both the buccal and lingual surfaces (Demi Plus, Kerr). All samples were light cured from occlusal surface for an additional 20 seconds following removal of the cementation load.

Figure 2. Completed samples for intact IPS e.max (left) and Lava Ultimate (Right) groups.

Following cementation, each crown was numbered 1-40 for each material. A random number generator program was used to select samples for the intact and repair groups.

An average endodontic access preparation was made for a 4 canal mandibular first molar with the assumption that a 4 canal molar may require a slightly larger access preparation than for 3 canals. Access preparation was started with a course grit (150μm) modified flat-ended tapered diamond bur until the underlying die was reached. (Neo Diamond, Microcopy Dental). The access outline was then completed with a medium (100-110μm) grit round-ended tapered diamond which was rated to have “good” cutting efficiency according to Qeblawi et al.[8] Originally, the medium diamond was intended to

be used for the entire access, but was found to dull too quickly at the tip to fully penetrate e.max crowns. NeoDiamonds were chosen for their single use application. A resin coping (Pattern Resin LS, GC America) of the initial access was made in order to facilitate uniform access preparations. The pattern was used to stencil the access outlines on each crown with a Sharpie marker which wouldn't wash off with water spray. All access preparations were completed by one provider with high speed rotary handpiece under copious water irrigation.

Prior to repair, all access cavities were cleaned with 37% phosphoric acid gel, rinsed and steam cleaned. For the e.max repair group, 9.6% hydrofluoric acid gel (PulpDent Corp.) was applied selectively to the crown access preparations for 20 seconds, rinsed and steam cleaned. Silane (Monobond Plus, Ivoclar Vivadent) was selectively applied to the crown portion of the endodontic access preparations for 60 seconds in both groups. Primer and adhesive (Optibond FL, Kerr Dental) were applied to the entire access preparations per manufacturer's instructions. Unidose packets were used to assure freshness for each sample. Access preparations were restored with dual cured, bulk fill core build-up composite resin (Luxacore Dual, DMG America). The composite was shaped to follow the cusp and fissure inclines before polymerizing with LED light (Demi Plus, Kerr America).

Following sample preparations, all samples were subjected to an axial load on the occlusal surface. A hydraulic testing machine (858 Mini Bionix II, MTS Systems Corp.) was used to apply the axial load. The loading piston was positioned toward the center of each crown and contacted both the crown and composite access repair (Fig. 5). Failure was determined by the first drop in axial load and was confirmed with simultaneous visualization of crack formation. The force in newtons (N) was recorded at the time of failure. Statistical analysis was performed using a Wilcoxon rank sum test.

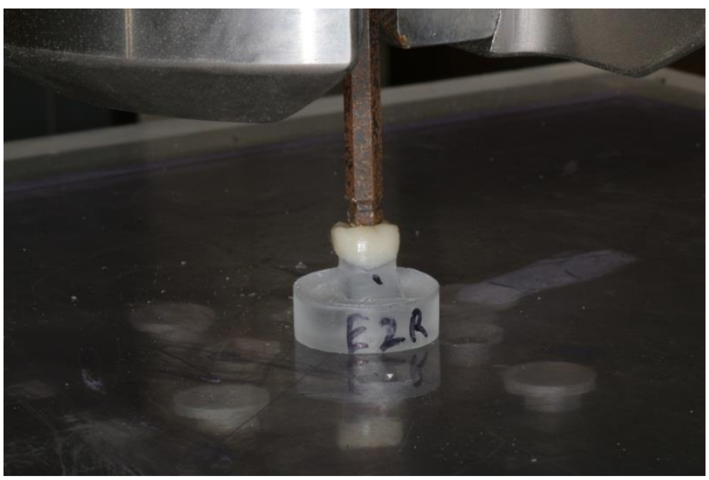

Figure 5. Positioning of sample for axial loading with The 858 Mini Bionix II.

RESULTS

The load-to-failure data with standard deviations are shown in Table 1. The mean load to failure ranged from 1204 N (intact LU) to 2317 N (intact e.max). A comparison of mean load to failure among the four test groups is depicted in Figure 6. Six of the intact e.max samples reached the program limit for load value and thus had very similar values between 2714 N and 2716 N. This is evident by the lack of an upper wisker for that group in figure 8. The minimum value was observed in the repaired Lava Ultimate group at 576 N. The repaired Lava Ultimate group showed the largest range (576 N – 2408 N).

The load to failure test yielded data that was not normally distributed for the repaired Lava Ultimate group. Because of this, a Wilcoxon rank sum test was chosen for analysis. Based on the

Wilcoxon rank sum test, the breaking force was significantly higher for the IPS e.max CAD compared to Lava Ultimate for both intact and repaired groups. (median=2485 vs. 1138 for intact, $p<0.001$, and median=1915 vs. 1164, $p<0.001$ for repaired). For e.max CAD, the breaking force was significantly higher for intact group compared to repaired group (median=2485 vs. 1915, $p=0.002$). However, there was no significant difference between intact and repaired groups for Lava Ultimate (median=1138 vs. 1164, $p=0.860$). Median failure loads are depicted in figure 7.

Test Group	e.max Intact	e.max Repaired	Lava U. Intact	Lava U. Repaired
Mean	2317	1904	1204	1262
Std. Dev.	475	316	279	476
Min	1239	1025	931	576
Median	2485	1915	1138	1163
Max	2716	2523	2199	2408
Offset	0.5	2.5	1.5	1.5

Table 1. Descriptive statistics for the failure load of four test groups

Although the central tendency of the distribution did not differ between intact and repaired for Lava Ultimate, there was more variability (larger standard deviation) for the repaired samples than for the intact samples (values ranged from 576-2408 for the 20 repaired samples compared to 931-2199 for the 20 intact samples, and std=476 vs. 279, $p=0.024$).

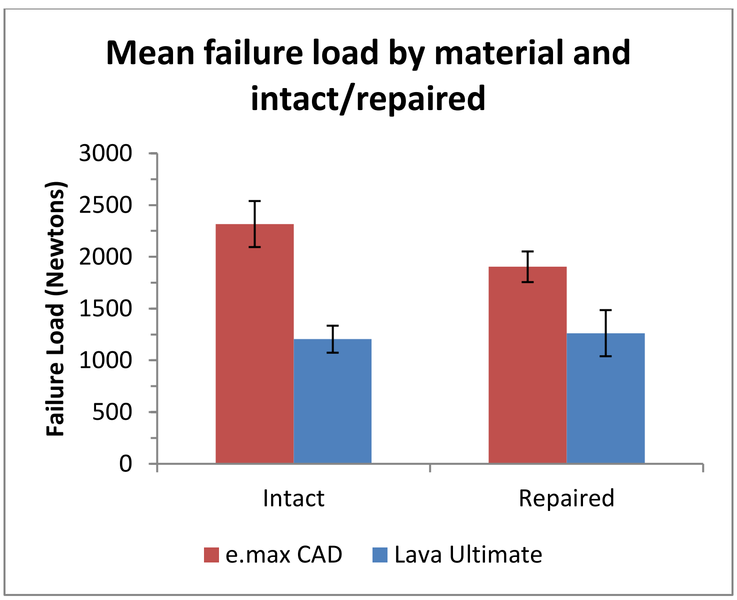

Figure 6. Failure load (N) according to material type (e.max vs. Lava Ultimate) and condition (intact vs. repaired). Error bars represent an approximate 95% confidence interval on the mean.

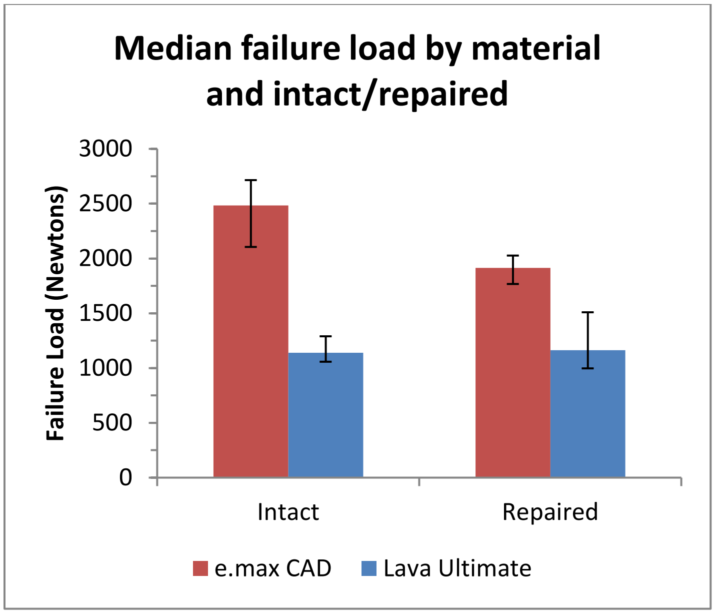

Figure 7. Failure load (N) according to material type (e.max vs. Lava Ultimate) and condition (intact vs. repaired). Error bars represent an approximate 95% confidence interval on the median.

In all cases, the fractures observed only included the crown and not the resin die. Resin dies remained effectively undamaged. There was no evident fracture pattern amoung the e.max groups or the repaired Lava Ultimate group. However, a fairly common fracture pattern was observed for the intact Lava Ultimate in which the mesial lingual surfaced sheared off obliquely. The Luxacore repair material for a number of the repaired samples remained intact. The Luxacore repair material seemed to remain intact if the crown fractured at a relatively low force value. However, repaired samples that fractured at higher values often showed crushing and chipping damage to these composite access repairs. In all cases, the cement bond ultimately failed between the fractured crown segments and the underlying resin die.

DISCUSSION

The hypotheses predicting that there would be no difference between the intact and repaired groups had to be rejected for the e.max test groups, but held true for the Lava ultimate groups. The hypothesis predicting that there would be no significant difference between the e.max and Lava Ultimate test groups also had to be rejected.

The finding of a significant difference in e.max CAD repaired and intact groups is contrary to previous studies.[8, 13] However, this may be explained by revisiting the fracture patterns observed in the present study. In all samples, the crowns fractured with no apparent damage to the underlying resin die. In all cases, no fragments remained adhesively bonded. It could be assumed that the adhesive bond between the crowns and dies was not very strong or may have been disrupted during endodontic access.

One factor that could have contributed to a weak adhesive bond could be the highly polymerized nature of the milled resin dies. Another factor could have been that an acidified primer/adhesive system was used. Typically ionic bonding of acidified monomers to calcium in the hydroxyapatite structure during application will help to decrease the acidity during setting.[16] However, when in contact with the resin die substrate, the primer/adhesive may have remained more acidic interfering with bond strength. A further shortcoming could have been that a 150 μm grit diamond was used for the initial crown perforation since the 100-110 μm grit diamonds were not efficient enough to initially

pierce the e.max crowns. NeoDiamond makes a 130µm grit tapered "endo access" with a round, ball tip that may have be better suited for access of strong ceramics.

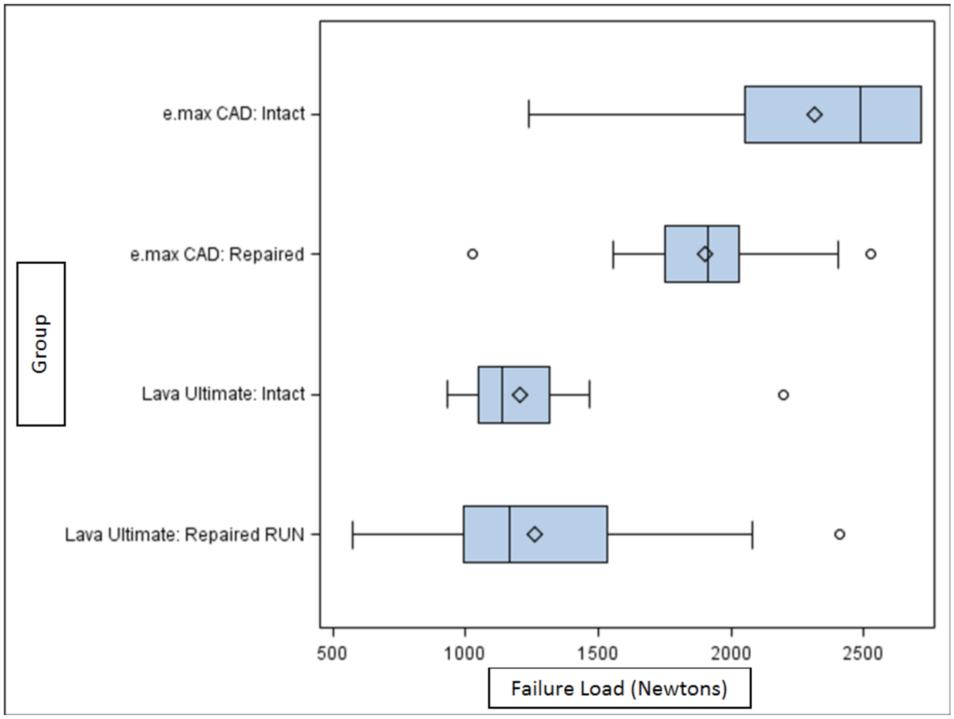

Figure 8. Box plot demonstrating distribution of failure loads for each of four test groups. Diamonds indicate the means. Upper and lower bounds of box indicate 75th and 25th percentiles of interquartile range, respectively. Upper and lower whiskers indicate min and max values with outliers indicated by circles.

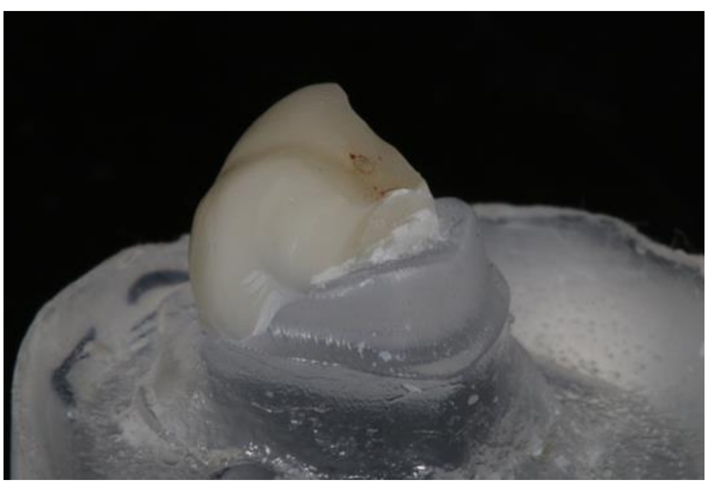

Figure 9. Fracture pattern showing catastrophic failure of the crown material with intact resin die.

Some other potential limitations to this present study are that it didn't simulate potential sources of bond fatigue or degradation as would occur intraorally. Some have advocated that cyclic loading prior to load to failure testing may be more clinically meaningful.[13] One study demonstrated

significantly decreased failure loads for all-ceramic crowns following cyclic loading in both dry and wet testing environments .[17]

To the authors' knowledge this is the first study to test the effect of endodontic access in anatomical mandibular molars for these two materials. The anatomical differences in maxillary and mandibular molars could lead to differences in how well their crowns withstand occlusal loads following endodontic access repair. The most common fracture pattern for the intact and repaired lava ultimate crowns involved the lingual cusps which is consistent with reported clinical fracture patterns for mandibular molars.[18, 19] This must be kept in mind during access; and it seems prudent to minimize extension towards the lingual cusp tips.

Though significant differences in failure loads were observed amoung some of the test groups in this study, mean and median failure loads were still arguably sufficient to withstand normal occlusal forces. One commonly quoted study found that average maximum occlusal force of test subjects equated to about 720 N. However, they also reported that typical occlusal loads during chewing and swallowing were only about 40% of one's maximum occlusal force.[20] One report found that a weightlifter with hypertonic muscles of mastication was able to generate a biting force of about 4,339 N which was about 6 times that of normal averages for non-bruxing test subjects. [21] This highlights the importance of recognizing possible parafunctional habits when deciding whether or not to repair a crown following endodontic therapy.

Though there was no significant difference between the intact and repaired Lava Ultimate groups, this result needs to be interpreted with caution due to the large variability in the repaired group. Though most of the repaired Lava Ultimate crowns fractured at values above average occlusal loads, a few of the samples did have values lower than 720 N. More research is need to establish whether this trend was unique to this study or is indicative of variability in the Lava Ultimate material itself.

At present, there is no consensus on whether or not an all ceramic crown needs to be replaced following endodontic access. With the ever increasing array of monolithic ceramic and resin-ceramic hybrid CADCAM materials, the question of whether to repair or place is likely to become only more convoluted. This and other recent studies might suggest that repair may be feasible.[8,13] However, as previously mentioned, the provider must be aware of clinical factors that could affect prognosis such as the type and grit of the bur used, the extension of the access preparation and parafunctional habits of the patient. With any treatment, informed consent is paramount and the patient should be allowed some autonomy in the decision as well.

REFERENCES

1. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications in fixed prosthodontics. J Prosthet Dent 2003; 90: 31-41.
2. Cheung GSP. A preliminary investigation into the longevity and causes of failure of single unit extracoronal restorations. J Dent 1991; 19: 160-3.
3. Trautmann G, Gutmann JL, Nunn ME, Witherspoon DE, Shulman JD. Restoring teeth that are endodontically treated through existing crowns. Part 1: survey of pulpal status on access. Quintessence Int 2000; 31(10): 713-8.
4. Michanowicz AE, Michanowicz JP. Endodontic access to the pulp chamber via porcelain jacket crowns. Oral Surg Oral Med Oral Pathol 1962; 15: 1483-8.
5. Sutherland JK, Teplitsky PE, Moulding MB. Endodontic access of all-ceramic crowns. J Prosthet Dent 1989; 61: 146-9.
6. Cohen BD, Wallace JA. Castable glass ceramic crowns and their reaction to endodontic therapy. Oral Surg Oral Med Oral Pathol 1991; 72: 108-10.
7. Haselton DR, Lloyd PM, Johnson WT. A comparison of the effects of two burs on endodontic access in all-ceramic high Lucite crowns. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000; 89: 486-92.

8. Qeblawi, D, et al. The effect of endodontic access preparation on the failure load of lithium disilicate glass-ceramic restorations. J Prosthet Dent 2011; 106(5): 328-336.
9. Sabourin CR, Flinn BD, Pitts DL, Gatten TL, Johnson JD. A novel method for creating endodontic access preparations through all-ceramic restorations: air abrasion and its effect relative to diamond and carbide bur use. J Endod 2005; 31: 616-9.
10. Davis MW. Providing endodontic care for teeth with ceramic crowns. J Am Dent Assoc 1998; 129: 1746-7.
11. Wood KC, Berzins DW, Luo Q, Thompson GA, Toth JM, Nagy WW. Resistance to fracture of two all-ceramic crown materials following endodontic access. J Prosthet Dent 2006; 95: 33-41.
12. Bindl A, Lüthy H and Mörmann W H. Strength and fracture pattern of monolithic CAD/CAM-generated posterior crowns. Dental Mater 2006; 22: 29-36.
13. Bompolaki D, Kontogiorgos E, Wilson J, Nagy W. Fracture resistance of lithium disilicate restorations after endodontic access preparations: an in vitro study. J Prosthet Dent 2015; Article in Press.
14. Awada A, Nathanson D. Mechanical properties of resin-ceramic restorative materials. J Prosthet Dent 2015; 114: 587-93.
15. Frankenberger R, Zeilinger I, Krech M, Mörig G, Naumann M, Braun A, Krämer N, Roggendorf MJ. Stability of endodontically treated teeth with differentially invasive restorations: adhesive vs. non-adhesive cusp stabilization. Dental Mater 2015; 31: 1312-20.
16. Van Meerbeek B. Mechanisms of resin adhesion-dentin and enamel bonding. Inside Dentistry 2008; 2(1): www.dentalaegis.com/special-issues.
17. Borges GA, Caldas D, Taskonak B, Yan J, Sobrinho LC, De Oliveira WJ. Fracture loads of all-ceramic crowns under wet and dry fatigue conditions. J Prosthodont 2009; 18: 649-55.
18. Eakle WS, Maxwell EH, Braly BV. Fractures of posterior teeth in adults. J Am Dent Assoc. 1986 Feb; 112(2): 215-8.
19. Bader JD1, Martin JA, Shugars DA. Incidence rates for complete cusp fracture.Community Dent Oral Epidemiol. 2001 Oct; 29(5): 346-53.
20. Gibbs CH, Mahan PE, Lundeen HC, Brehnan K, Walsh EK, Holbrook WB. Occlusal forces during chewing and swallowing as measured by sound transmission. J Prosthet Dent 1981; 46: 443-9.
21. Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite strength. J Prosthet Dent1986; 56: 226-9.